

UNCLASSIFIED

Defense Technical Information Center
Compilation Part Notice

ADP011290

TITLE: Remote Ultrasonic Classification of Fluids Using the Acoustic Resonance Characteristics of the Container

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Proceedings of the Resonance Meeting. Volume 1. Transcripts

To order the complete compilation report, use: ADA398263

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:

ADP011275 thru ADP011296

UNCLASSIFIED

REMOTE ULTRASONIC CLASSIFICATION OF FLUIDS USING THE ACOUSTIC RESONANCE CHARACTERISTICS OF THE CONTAINER

DIPEN N. SINHA,¹ GREGORY KADUCHAK,¹ MICHAEL J. KELEHER²

¹LOS ALAMOS NATIONAL LABORATORY

²DEFENSE THREAT REDUCTION AGENCY

ABSTRACT

A novel technique for classifying fluids in sealed, metal containers at large stand-off distances has been developed. It utilizes a recently constructed air-coupled acoustic array to excite the resonance vibrations of fluid-filled vessels. The sound field from the array is constructed by transmitting a high frequency modulated carrier wave which is parametrically self-demodulated along its propagation path in air. The array has a narrow beam width and an operating bandwidth of greater than 25 kHz. The vibrations are detected using a laser vibrometer in a monostatic configuration with the acoustic source. Experiments demonstrate resonance classification of the fluid-filler inside steel vessels is possible with incident sound pressure levels of the demodulated wave as low as 80 dB at the container location. Preliminary experiments demonstrate stand-off distances of greater than 3 m.

TRANSCRIPT

[Transparency 1]

DR. SINHA: What I want to talk about is how one can identify chemicals or liquids in sealed containers from a distance.

[Transparency 2]

Before I do that, let me explain why we want to do such things. This is what I had talked about two years ago at this conference, how we try to identify chemical warfare agents and other toxic chemicals, inside various types of munitions.

This is a noninvasive technique, where you have the transducers outside and one does not need to drill holes into the container, but one can still derive various physical properties of the chemicals. In this figure, I have shown sound speed, sound attenuation and density, all measured noninvasively.

Based on these physical characteristics one can uniquely identify the chemicals inside a sealed container. We built a little portable instrument, battery-operated, and it does pretty much the kinds of measurements you heard about this morning. It sweeps through a frequency range that sets up an interference pattern inside the liquid. Both in-phase and quadrature measurements between 1 and 10 MHz are made that provides a spectrum from which one determines all the physical properties. That is what we had done previously.

This instrument is now delivered to the Department of Defense and is being currently used in various places.

[Transparency 3]

The next phase of the work was to do the measurements from a distance instead of getting close to the items containing hazardous chemicals. The first question is why is this capability needed? There are various situations, very hazardous conditions, where you have toxic vapors or radioactivity and you do not want to get close to the containers but you still want to identify the chemicals or figure out what is inside.

Some of the usages you can think of are such as the waste storage facilities at Rocky Flats or the WIPP (Waste Isolation Pilot Plant) facility in New Mexico. There are also law-enforcement situations where government agents run into places where they find abandoned containers, or whatever, and they want to find out what is inside before they can properly dispose of these.

The major reason we first got involved in this development project is because our application was chemical weapons compliance monitoring, where one needed to find out during challenge inspection or otherwise, what kind of chemical is inside various munitions, pipes, containers, etc.

There are also applications in the chemical and various other industries. Firefighters are very interested in this sort of thing. Before they go into a burning building they would like to know, if they see a drum or a container, whether it contains any flammable liquid.

[Transparency 4]

This picture shows Greg Kaduchak making measurements on real chemical munitions. He does not really enjoy doing this kind of work wearing masks and taking data. This is one of the reasons we decided to come up with this remote technique.

[Transparency 5]

Let me first mention the different principles involved in this technique. There are 3 components to this whole approach. The first thing is, we need a way to project sound and to aim the sound in a certain direction on to the target instead of exciting the whole room and becoming a nuisance.

Because of the nonlinearity of air, if you put high-intensity sound, the waves that go through, as you can see, distort, and because of this nonlinearity and distortion, you can generate harmonics, you can have self-demodulation, shock-front development, etc. These phenomena are very well understood and worked on for many, many years in underwater acoustics.

We have taken pretty much the same principles and used them in air.

[Transparency 6]

Let me show you exactly how that is done. These are the two approaches we tried. The first approach is to start with two high-frequency transducer arrays. These are at two slightly different frequencies around 200 kHz, so the beam is very well defined. The two beams mix in the air. When it mixes, you end up getting the difference frequency and the sum frequency.

The sum frequency gets absorbed as it goes through the air because air is highly absorbing at such frequencies, and so you are left with only the difference frequency. The difference frequency, then, resonantly interacts with the container and sets up guided waves. I have to thank Todd and Phil Marston, they just described the theory before me, and so I do not have to go through that again. We pick up the resonant vibration of the container surface with a laser vibrometer. The advantage of this technique is that the beam is so well collimated, if you stand anywhere close by and not directly in the path of the beam, you cannot hear a thing, it is completely inaudible, but you can still make the measurements.

[Transparency 7]

The second approach is a little more efficient than the first one, because the sound interaction volume is very small when you have two separate beams mixing at an intersection region. In this second method what we have is a parametric array of transducers that is operated at a high frequency, around 200 kHz (217 kHz, to be exact) and we amplitude-modulate it by multiplying the high frequency with a lower frequency.

As the beam propagates through the air -- here I am showing blue as the high frequency -- it self-demodulates and you end up with the low frequency, just the low frequency modulating signal, which is exactly what we need. We sweep the modulating frequency and therefore you

can excite a whole resonant spectrum of the container. From this spectrum, then, we can derive, just as before, the chemicals inside.

DR. SMITH: What is a parametric array?

DR. SINHA: When you generate low frequency by taking advantage of the parameters of the air, essentially the mixing, and the nonlinearity.

DR. SMITH: How remote is this?

DR. SINHA: I am coming to that.

[Transparency 8]

Let me first describe this array, how we build it. There are many ways of doing it, but we wanted the quickest and cheapest way of doing it, so we bought off-the-shelf commercial air transducers from AIRMAR. These are about \$20.00 apiece.

Greg drilled regularly spaced holes in a round plastic plate and we, just like a Lego set, stuck in a whole bunch of these air transducers in there, and that is the array, essentially. The array is driven at 30 V or less. You can get pretty decent directivity.

[Transparency 9]

This is the beam spread of an array of that size at a low frequency, such as at 13 kHz, but when you use this parametric array with the mixing in air, the beam profile is much, much narrower. It is very directional.

[Transparency 10]

The distance here is about 3 meters. We have gone as far as about 5 meters. Here is the parametric array. We start with the high frequency and end up with the low frequency. Here I have two steel containers, just a cutout of a 155-mm artillery shell (the picture I showed you in the beginning). There are two liquids, isopropanol and ethylene glycol. Here is the laser vibrometer for the Doppler type of measurement. We sweep through the modulating frequency, so we can get a resonant spectrum.

[Transparency 11]

The setup is also very simple. Here's a function generator, the output from which goes through a power amplifier and boosted to about 30 V and drives the parametric array. The laser vibrometer picks up the signal and the output goes through a homodyne detector, which is very much like a tracking filter, with a 100 Hz bandwidth. A laptop computer is used to display the spectrum.

[Transparency 12]

Here is a picture of the actual setup. This is a smaller version of this array. These are the two steel containers I mentioned earlier. The yellow object in the picture is the laser vibrometer. The distance between the containers and the laser vibrometer is about 10 feet in this picture.

[Transparency 13]

The advantage of this laser vibrometer is that there are no mirrors attached to the containers, so it can be any surface that the laser beam is shining on. The red dot is the laser beam. We put antifreeze here, because it is colorful, so you can see the difference between the two liquids. The reason there is a little core, it is called a burster core, is that is where the explosive goes inside chemical ordnance.

The dimensions are all given here for these containers. We have tried various kinds of containers; these are meant for quantitative measurements.

[Transparency 14]

This is pretty much what you heard from the previous speakers. Instead of underwater, this is in air. This launched the sound wave that generates these Rayleigh modes. This is the anti-symmetric a_0 mode that Todd talked about previously. It goes around the circumference and sets up resonances each time this resonance condition is fulfilled, so you get a series of resonances, but nicely spaced according to the sound speed in the wall.

[Transparency 15]

This is pretty much the same picture that Todd had. The phase velocity is the red line here, the dotted line. These are the two phase-velocities when you have that steel container filled with isopropanol and ethylene glycol, and this is the radiation damping for the particular container that I showed. This radiation damping kind of tells you what the efficiency of coupling of sound is with the containers. It is a little difficult to see the difference between the two liquids, because these are absolute values.

[Transparency 16]

Let me show you the difference between the two and now it is much more obvious. This is the phase velocity difference between isopropanol and ethylene glycol as a function of frequency. These are derived from theory.

[Transparency 17]

I would like to show you the measured data now. This is the actual spectrum that we get from the output of the laser vibrometer. If you notice, these resonance lines are regularly spaced, with the spacing increasing continuously. This is because the sound speed is increasing with frequency.

On the top is shown the theoretical prediction for the same measurement. Agreement between experiment and the theory -- this is the a_0 mode -- looks pretty good. That means you can indeed back out the properties, the density, sound speed, et cetera, from the observed spectrum.

[Transparency 18]

This is actually a computer screen dump from the data as we take them. I have blown up the area just to show one resonance peak, how it shifts between ethylene glycol and isopropanol. Once it sweeps through, that takes only about 20 seconds, the computer program then comes up with a match.

[Transparency 19 -- unavailable at time of printing]

These data are from a contact measurement, not non-contact, just to show how, if you have different viscosities or attenuation, how the resonance Q's are damped. By measuring the resonance Q -- here, GB is Sarin and H is Mustard (the other kind, not the kind you put in your sandwich) -- it is possible to determine attenuation, too. Once you get sound speed, density, and attenuation, you can pretty much identify a lot of chemicals.

What I have just shown you is very preliminary work; it has a long way to go.

[Transparency 20]

We also tried to see if we could determine what the liquid level is inside the container. Now, instead of sweeping through the frequency we pick just one resonance frequency and move the laser beam up and down. You can see there is a dramatic change in the amplitude as you cross the liquid level. So, essentially from 10-12 feet away you can determine the liquid level, too.

[Transparency 21]

It is really possible, from a distance, to excite various guided waves on a container, look at their interaction with the fluid inside and identify chemicals. What limits our distance, how far we can go? It is the laser vibrometer. The one we currently have goes up to only about 25 kHz and about 15 feet is its limitation -- it is a pretty "el-cheapo" brand.

There are other laser vibrometers that have a range up to 30-35 feet. That pretty much limits how far you can go, because you can always jack up the power level in your parametric array within reason. We are nowhere near any upper limit of power that can be used. One thing I forgot to mention is the power level is about 85 dB near the low frequency that is at the target. There is a lot of absorption but, still, that was enough, 85 dB, to excite resonances and be picked up.

If you have better instrumentation, there is no reason why you cannot extend the range further.

This technique can also be used for standard nondestructive testing remotely. One can look for wall integrity, thickness, if you have rusting, corrosion. These conditions can probably be determined. There are lots of applications that one can think of but I focused on only one.

DR. SMITH: _____ levels? I may have read that graph wrong, but on your amplitude versus _____ graph, you have got a region where there is liquid and then you have an air gap and then no liquid?

DR. SINHA: No, no. This is the liquid and this is the air gap -- I mean, not the air gap.

DR. SMITH: On the graph.

DR. SINHA: On the graph? Oh, this is a very noisy signal, so it is just average; it is just a square wave. You move the laser beam up and down, the signal just bounces up and comes down; it is a dramatic change. That is all I am showing there.

DR. LEISURE: How does the technique depend on atmospheric conditions, humidity and so on?

DR. SINHA: It does not, as far as we can tell, but in Los Alamos the air is very dry. I do not think humidity has much effect. By the time you get that kind of power, the effect of humidity is very minimal. It does affect the sound speed a little bit and maybe a little bit of the attenuation, but it should not be very dramatic.

DR. MARSTON: You showed a picture of a container with an empty core in the middle. If there were another chemical in there, would you see 2 sets of resonances for each chemical?

DR. SINHA: No, because it is already so insensitive -- I mean, the sound wave goes around the outer casing, it really would not see the inside. But if I am doing contact measurements, then it has the sensitivity, and you can pick such things up but from a remote measurement it is very difficult.

DR. HARGROVE: It would be possible, if I were trying to get around a chemical weapons ban, to shield the resonance technique?

DR. SINHA: In principle, yes

DR. DARLING: How sensitive is this to the actual container? I got the impression that you needed to have some sort of standard measurement. It is independent?

DR. SINHA: We can put in artillery shells or anything. This was a good thing to do, the theoretical calculations, so we needed exact dimensions to really match against.

DR. DARLING: So you can tell from any container the contents?

DR. SINHA: Sure.

DR. DARLING: Just from previous measurements and physical properties?

DR. SINHA: Yes, unless it is plastic, very soft, that may be different.

DR. DARLING: It takes a surface normal to your laser beam to see --

DR. SINHA: This does not depend on the actual reflection back to the vibrometer. All it has is a kind of little telescope, it looks at that spot. It is not a direct reflection back and you do not need a mirror, either. If it is completely absorbed, sure, you are not going to see anything.

DR. MARSTON: I have 2 questions. One, the AIRMAR transducer, what was the technology?

DR. SINHA: Ordinary piezo with the little matching layer in front of it. That is about it.

There is a lot of room for improvement. We are talking to various companies that have special capacitance types of transducers, there is one company in Canada, and another just started in San Diego. These are very expensive, approximately \$2000 for a single transducer. We did try these; we just did not make an array out of them.

What we have done is rather inefficient. It was just a demonstration to show that the technique does work.

DR. HARGROVE: I want to caution you against saying that you can deliver more sound at some distance by just turning up the source. I have spent too much time with people who want to do acoustic cannons and all kinds of stuff like that. There is a nonlinear saturation; there is a limit for any given medium of distance as to much you can get from here to there.

DR. SINHA: That is true, except that I am not depending on the higher frequency. After it mixes --

DR. HARGROVE: I do not care what frequency.

DR. SINHA: I am not going for unlimited. I am just talking about 30 feet versus 12 feet. There is no way you are going to go a mile or anything. No, that is not going to happen, plus the beam would spread too and you cannot focus it any more. It needs to be within reason.

DR. MARSTON: The second part of my question is what were the displacement amplitudes you typically measured with the vibrometer?

DR. SINHA: Probably anywhere from a 100th of a micron to a 10th of a micron, roughly. The vibrometer is very sensitive but, also, you saw the data that it is pretty noisy, too. The one made by Polytech has a much cleaner signal, but it is 3 times more expensive.

DR. LEVY: I am slightly confused by the data that show here is the beam. I saw a lot of other beams. Could you go back to that?

DR. SINHA: Sure.

[return to Transparency 17]

When you excite those, the a_0 waves are the ones that are really developed in the most efficient way, so those are the peaks that are much stronger, but there are smaller ones, too, there are other modes that may be generated.

DR. LEVY: You showed another graph, too.

DR. SINHA: The other graph was just an experiment straight from the computer screen, the raw data.

[return to Transparency 18]

This is the peak that shifts to this position when you have ethylene glycol versus isopropanol and I was showing how large the shift is. That is what I was showing. But if you are looking at this little one, there is some noise and there could be some other modes in there.

DR. LEVY: Those nice-looking peaks halfway between ethylene glycol and isopropanol.

DR. SINHA: You mean these? There can be a lot of other resonances (e.g., lengthwise instead of circumferential), because, it is a finite size.

DR. LEVY: How do you distinguish which one is ethylene glycol and the other one is isopropanol?

DR. SINHA: These are very large. These resonance peaks are many times larger than the smaller peaks. Also, if I turn on the filter, those little ones really go down. It is very easy to identify the ones that I am looking for. This is only one peak --

DR. LEVY: But what makes them small, the filter?

DR. SINHA: If you want to get rid of the noise, there is some real resonance and the other is just noise in the electronics, probably the laser vibrometer, which I do not have too much control over.

There are other modes being generated, too, sure. We just have not modeled all the other ones. We took the simplest one and it agrees with theory and that was good enough to do the job. As I mentioned, this is very preliminary work and a lot more really can be done.

PARTICIPANT: I was surprised that it does not matter what the shape or size of your container is. It is inconceivable that you do not need a base cylinder to measure before you know what is inside of it.

DR. SINHA: All the munitions that we deal with, we know their dimensions.

PARTICIPANT: So you do not need a reference shell?

DR. SINHA: No, you do not need a reference shell. All you need is the actual measurement. If I know it is made of steel, that is all I really need, or it is made of aluminum. Most of the chemical munitions are made of only a few materials, so this is not absolutely arbitrary.

Your question is if it is an absolutely arbitrary system, how does one do it? That is going to be very difficult.

Thank you.